

PROCEEDINGS
OF
THE INSTITUTE OF RADIO
ENGINEERS
(INCORPORATED)

VOLUME 4

1916



EDITED BY
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PUBLISHED EVERY TWO MONTHS BY
THE INSTITUTE OF RADIO ENGINEERS
(INC.)

ONE HUNDRED AND ELEVEN BROADWAY
NEW YORK

EXPERIMENTS AT THE U. S. NAVAL RADIO STATION DARIEN, CANAL ZONE*

By
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The three towers for the Darien radio station were completed early in 1915. These towers are of the self-supporting type, each 600 feet (182 meters) high and approximately 900 feet (273 meters) apart, forming a triangle. The acceptance tests of the station gave another opportunity for carrying out long distance experiments in radio transmission which are, in a sense, a continuation of those earlier experiments carried on at Brant Rock and at Arlington which have already been described.¹

The experimental work was begun in March, 1915. At this time the permanent antenna which consists of a triangular net of wires without spreaders, having a capacity of $0.01 \mu f.$ and an effective height of 480 feet (146 meters), was not in place, so the receiving during the first month was carried on with a 4-wire, flat-top antenna 400 feet (122 meters) long and 10 feet (3 meters) wide, stretched between two of the towers. The effective height of this antenna was calculated to be 480 feet (146 meters), and its capacity $0.003 \mu f.$ The ground system of the station consisted of a buried wire net covering the whole space inside the towers and extending to a considerable distance outside.

In the receiving experiments, a de Forest oscillating audion² with beat tone reception was used as a detector. This form of detector had been under investigation at the Naval Radio Laboratory for about a year before the Darien experiments were begun and had been found to give practically uniform sensitive-

*Presented before the Washington Section of The Institute of Radio Engineers, November 27, 1915.

¹"Bulletin, Bureau of Standards," 7, p. 315. Reprint 159, 1911.

"Bulletin, Bureau of Standards," 11, p. 69. Reprint 226, 1914.

²"Proc. Inst. Radio Engineers," 3, pages 215 and 261, 1915.

"Journ. Amer. Soc. Naval Engineers," 27, page 358, 1915.

ness when properly adjusted,¹ except in the case of bulbs which, on account of imperfect exhaustion, behaved abnormally. Careful comparisons had been made of the relative sensitiveness of the oscillating audion and the electrolytic, the experiments showing that the normal oscillating audion gives from five hundred and one thousand audibility (depending on the telephone note) for unit audibility with the electrolytic.² It was also found that while the electrolytic and non-oscillating audion give telephone audibilities proportional to the square of the received current, the oscillating audion responds in proportion to the first power of the received current. Aside from the matter of telephone note, the sensitiveness seems to be the same for undamped and for damped oscillations, except when the spark trains are very short.

Figure 1 shows the circuits used for reception. It will be noted that the secondary receiving circuit is connected to the

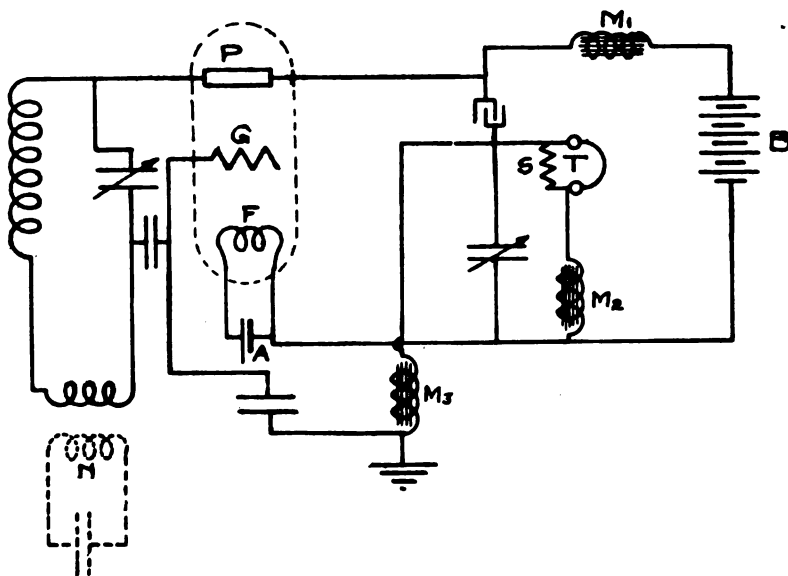


FIGURE 1

intermediate or grid electrode *G* in the audion, and to the plate electrode *P*, forming the ultraudion connection. The fila-

¹The adjustment for greatest sensitiveness requires special skill on the part of the operator. Quantitative readings taken by untrained men will give considerably lower sensitiveness.

²"Bulletin, Bureau of Standards," 11, page 77. Reprint 226, 1914.

ment F is heated to incandescence by the storage battery A , while a steady flow of electrons is produced by the dry battery B . The telephones used in the experiments are placed in a shunt circuit in parallel with the audion, instead of in series with it as the more usual custom. The atmospheric disturbances are slightly less troublesome with this connection, and the sensitiveness to signals remains the same. The circuit described is designated the plain audion circuit, and for its best action the coupling between the antenna and secondary must be close, since the oscillating audion reaches its full sensitiveness only when the local oscillations are reduced in intensity by withdrawing energy into some neighboring circuit.

The sensitiveness may be increased some three or four times above that of the plain audion circuit by the use of a sensitizing circuit N for reducing the amplitude of the local oscillations. This consists simply of an inductance and capacity coupled to the secondary and tuned close to the resonance point. By the use of this circuit it is possible to work with a looser antenna coupling without loss of sensitiveness.

The strength of the received signals was measured by the shunted telephone method, the audibility of the signals being expressed in telephone current. The non-inductive resistance S (Figure 1) is placed across the telephone leads and the resistance reduced until the signal just remains audible. The unshunted telephone current is then

$$A = \frac{t+S}{S}$$

where t is the effective telephone resistance for the telephonic frequency used and S is the value of the shunt. The audibility A represents the ratio of the actual telephone current to the least audible telephone current of the same frequency. When the non-inductive shunt is placed across the telephones, it is necessary to have a choke coil M_2 or a second pair of telephones in series. On account of the effect of the observer's body, it is also necessary if the signals are strong, to earth one of the telephone leads thru a proper choke (2,000 ohm telephones). Which telephone lead should be earthed must be determined by trial.

Table I gives some of the results of the receiving experiments at Darien. As Arlington was the only station on which daily observations were made, the observations on its signals should be given much greater weight than the others in the table.

TABLE I

STATIONS RECEIVED AT DARIEN

	Distance Km.	I_s Amp.	λ Meters	h_1 Meters	R Ohms	W (Calc.) Watts	Audibility Calculated	Audibility Observed
Arlington.....	3,330	60	6,000	61 ²	23.2	$6.85 \cdot 10^{-8}$	7,500	5,000
Tuckerton.....	3,430	115	7,400	150	25.	$1.25 \cdot 10^{-6}$	32,000	10,000
Sayville.....	3,520	140	9,400	100	14.	$1.26 \cdot 10^{-6}$	32,100	7,500
San Diego.....	4,670	35	3,800	68	26.5	$1.63 \cdot 10^{-9}$	1,150	0-100
San Francisco (Federal).....	4,820	40	6,500	120	23.5	$4.65 \cdot 10^{-9}$	2,050	0-1,000
Honolulu ¹ (Federal).....	8,500	60	10,000	120	13.5	$4.16 \cdot 10^{-10}$	580	150
Nauen.....	9,400	150	9,400	150	29.	$9.95 \cdot 10^{-10}$	900	200
Eilvose.....	9,160	140	7,400	150	25.	$5.67 \cdot 10^{-10}$	705	200

¹Received on large antenna.² h_1 corrected from short range observations. For other stations h_1 is uncorrected.

All of the signals of less than one thousand audibility were very much affected by the atmospheric disturbances, probably being inaudible many times on this account alone.¹ Column 1 gives the approximate distances of the various stations from Darien, Column 2 the strength of sending antenna current. This, however, was not known reliably in all cases. Column 3 gives the wave length, 4 gives the estimated effective height of sending antenna, 5 the total effective resistance of the receiving system for the given wave length, 6 gives the calculated received watts, 7 the calculated audibility, and column 8 the observed audibility.

TABLE II

Audion Audibility	Received Watts	Audion Audibility	Received Watts
5,000	$3.05.10^{-8}$	60	$4.41.10^{-12}$
4,000	$1.96.10^{-8}$	50	$3.05.10^{-12}$
3,000	$1.11.10^{-8}$	40	$1.96.10^{-12}$
2,000	$4.40.10^{-9}$	30	$1.11.10^{-12}$
1,500	$2.75.10^{-9}$	25	$7.66.10^{-13}$
1,000	$1.23.10^{-9}$	20	$4.40.10^{-13}$
800	$7.84.10^{-10}$	16	$3.14.10^{-13}$
600	$4.41.10^{-10}$	12	$1.765.10^{-13}$
500	$3.05.10^{-10}$	10	$1.23.10^{-13}$
400	$1.96.10^{-10}$	8	$7.84.10^{-14}$
300	$1.11.10^{-10}$	6	$4.41.10^{-14}$
250	$7.66.10^{-11}$	5	$3.05.10^{-14}$
200	$4.50.10^{-11}$	4	$1.96.10^{-14}$
160	$3.14.10^{-11}$	3	$1.11.10^{-14}$
120	$1.765.10^{-11}$	2.5	$7.66.10^{-15}$
100	$1.23.10^{-11}$	1.0	$1.23.10^{-15}$
80	$7.84.10^{-12}$		

Table II gives the received watts corresponding to the various audibilities using the oscillating audion without sensitizing circuit, as deduced from the experiments at the Naval Radio Laboratory which showed that for unit audibility with the electrolytic, the oscillating audion gave an audibility of 1,000. The watt sensitiveness of the electrolytic was taken to be 12.25×10^{-10} watts² using telephones of 2,000 ohms resistance and a current

¹The normal disturbances at Darien except in the morning were so strong that with the telephones on the table a crackling rumble could be heard in all parts of the receiving room. To prevent the breaking down of the local oscillations due to these heavy atmospheric discharges, it was found necessary to earth the grid electrode of the audion thru a small capacity.

²"Bulletin, Bureau of Standards," 11, page 69, 1914. Reprint 226.

sensitivity of 5.10^{-10} amperes at a frequency of 1,000 per second. This table cannot lay claim to perfect accuracy as applied to the Darien receiving set, since it was derived from experiments with a different receiver, and it might be supposed that the sensitiveness of the oscillating audion might probably vary with the ratio of inductance and capacity. Experiments thus far made, however, do not indicate with certainty that there is any such variation. At any rate, it is safe to say that the values given in Table II are approximately correct.

All of the observations recorded in the table, except those on Sayville and Honolulu, were taken on the small receiving antenna during the month of March. A series of daily observations extending over a period of a week were taken on Honolulu early in May, using the large antenna. Tuckerton was measured about every second day during March, San Francisco, Nauen and Eilvese were measured only a few times so these observations have comparatively little value. San Diego with its short wave length coming all the way overland could not be expected to approach its calculated over-sea audibility. It will be noted that Arlington is the only station in which the observed audibility approaches the calculated, but in this case Arlington's effective height h_1 , was determined experimentally from observations made at near-by stations and is only about one-half of the height to the geometric center of capacity. If the effective heights of Tuckerton, Sayville and Honolulu were reduced in the same ratio, the agreement of their observed and calculated values would be nearly as good. The great weakness of the day signals from Nauen and from Eilvese is astonishing, as in Washington they come in with their full calculated audibility.

Beginning with May, regular observations on the received signals from Darien were taken at the Naval Radio Laboratory at the Bureau of Standards. The signals were received on a flat-top antenna 450 feet (130 meters) long, having a capacity of $0.00155 \mu f$ and an effective height of 100 feet (30 meters). This effective height is practically the same as that of the old harp antenna described in former papers, and has the advantage over the harp of having a much lower ground resistance at the longer wave lengths.

TABLE III

DARIEN RECEIVED AT THE U. S. NAVAL RADIO LABORATORY,
BUREAU OF STANDARDS

$h_1 = 146 \text{ m.}$ $h_2 = 30 \text{ m.}$ $I_s = 100 \text{ amp.}$ $\lambda = 6,000 \text{ m.}$
 $d = 3,330 \text{ Km.}$ $R = 75 \text{ ohms.}$ Calculated audibility = 3,600

	OBSERVED AUDIBILITY				Number of Obser- vations
	Total Average	Maximum	Minimum	Normal Average*	
1915					
May.....	8,700	20,000	1,000	3,100	11
June.....	33,000	100,000 (Estimated)	300	3,700	11
July.....	9,000	50,000	600	3,800	12
August.....	4,100	20,000	400	2,300	19
September.....	1,330	2,000	300	1,330	13
October.....	1,460	3,000	400	1,460	9
November.....	21,500	40,000	5,000	4
December.....	13,750	30,000	5,000	4

Table III gives the monthly averages of the results of these observations. A large number of measurements were made between May first and November first, and since that time have been taken weekly. During the summer, except in June, the general intensity was between 1,000 and 3,000 audibility, with occasional periods of greater intensity, going up to 30,000 or 40,000 audibility while on one or two occasions the intensity has been so great that the signals could be heard a hundred feet from the telephones without the use of any amplifying device. Since the first of November, the signals have been uniformly strong. The calculated value of audibility is given at the top of the table.

September and October are seen to be the months with the lowest averages. This is due not so much to exceptionally weak signals as to the fact that there were no periods of extraordinary intensity such as occurred in the other months.

One of the most interesting points in this table is the astonishingly high occasional values of the audibility, observed during June, July and August, a time of year which is generally supposed to be especially unfavorable for radio communication.

*The normal average excludes the occasional excessively high peaks of the audibility curve which are supposed to be produced by the same causes which produce the irregular and strong signals at night at shorter wave lengths. U. S. Naval Radio Laboratory.

Comparing the calculated values¹ of the Navy formula

$$I_R = 377 \frac{h_1 h_2 I_s}{\lambda d R} \varepsilon^{\frac{0.0018d}{\sqrt{\lambda}}}$$

and that of the Sommerfeld purely theoretical formula,

$$I_R = 377 \frac{h_1 h_2 I_s}{\lambda d R} \varepsilon^{\frac{0.0018d}{\sqrt{\lambda}}}$$

we find that the Sommerfeld formula would give 15 times audibility for Eilvese received at Darien, and 20 times audibility for Honolulu received at Darien. These values are so far below those observed as to support the conclusion in the paper last cited that, in order to represent the usual observed values an additional term must be added to the theoretical formula, representing energy reaching the receiving station by reflection.

It seems possible that the Sommerfeld formula represents the very lowest values of received signals, and that these are ordinarily strengthened by energy from the upper atmosphere the intensity of which would probably depend on the wave length. On this supposition, the scattering term of the empirical formula would represent the sum of these two effects which in their combination might very possibly introduce the square root of the wave length instead of the cube root, as indicated by theory.

U. S. Naval Radio Laboratory,
Washington, February, 1916.

SUMMARY: The results of measurements of the strength of received signals at Darien from a number of stations are given. A specially modified ultraudion circuit is used. The Austin-Cohen formula is found to give much closer agreement with the observations than the Sommerfeld formula. Relations between received current and audibility are given for the audion and ultraudion.

¹"Bulletin of the Bureau of Standards," 11, page 269. Reprint 226, 1915.

DISCUSSION

John L. Hogan, Jr.: This interesting paper of Dr. Austin's would have been of more value to me, and I think possibly to others of us, if a few specific points had been cleared up. I am sorry that Dr. Austin himself is not with us this evening, since he could without doubt explain the several relations of detector-organization sensitiveness which appear confusing.

The paper states that the oscillating audion, or auto-heterodyne, has been found to have from 500 to 1000 times the sensitiveness of the electrolytic detector, the exact ratio depending upon the telephone note. I do not understand whether this reference is to grouped-wave or to sustained wave reception. If the grouped waves were received, was the audion in the oscillating condition, and the group frequency tone destroyed, or was the tube in a critical condition and was amplification secured by regenerative action? If sustained waves were used for the comparison, was the electrolytic detector excited according to the heterodyne method, or was a chopper used?

At the end of the third paragraph of the paper it is stated that the oscillating audion or auto-heterodyne has the same sensitiveness, aside from the matter of telephone note, for slightly damped and for sustained waves. How are these measurements made, and what relation have they to the figures quoted above? Further, does this equality of sensitiveness hold when the sensitizing circuit N of Figure 1 is added? It is stated that the presence of this absorbing circuit increases the sensitiveness of the self-excited audion heterodyne by three or four times, giving apparently a total improvement in sensitiveness to a point some 4,000 times that of the electrolytic detector.

Since the ordinary amplification ratio of the single audion bulb is usually taken to be in the neighborhood of five, it would appear that Dr. Austin's work has been done under conditions in which the signals were continuously amplified by regeneration. This adjustment of circuits is notoriously unstable, and with it quantitative results showing consistent performance are very difficult to secure. The variation from day to day, or from one adjustment to an attempted repetition of it at some later time, is likely to be especially great when the regenerative audion is used to take measurements according to the shunted telephone.

With regard to table 1, it may be noted that the observed audibility ranges from one twentieth to one third the calculated

audibility. If the effective heights of the transmitting stations were halved, as suggested, somewhat better agreement would of course be secured. It appears to me, however, that one should consider the desirability of decreasing the assumed ratio of detector sensitiveness. If the sensitiveness of the ultraudion is taken to be only 500, instead of 1000 times that of the electrolytic, better agreement can be secured without the necessity of departing from the earlier conception of effective height. Until these measurements can be confirmed with so constant a device as the tikker, it would seem wise not to overthrow the relation between geometric and effective height which has been found to agree so well with quantitative results of many earlier observations.

This matter of checking ultraudion observations against tikker reception might also be borne in mind in attempting to pin down the causes for such tremendous variations in intensity as are indicated by table 3. Changes in received power so great as those implied by the observations of table 3 seem to indicate variations in net sensitiveness of the receiver, as well as changes of the medium between the two stations. Further, the effect of strong atmospherics, in reducing the apparent sensitiveness of receiving apparatus for telephone shunt observations, must not be underestimated.

The fact that in spite of a measured intensity of 5,000 audibility, it is very difficult for Darien to copy messages transmitted from Arlington, confirms the earlier indications that large numerical values of audibility to signal are useless in commercial radio telegraphy unless the intensity of response to strays is limited. In the absence of severe atmospheric disturbance, one can of course amplify feeble signals indefinitely, and in that way read messages which were entirely inaudible before successful telephone or radio frequency relays had been produced. When strays co-exist with the signals, however, amplification of the ordinary sort becomes futile. This indicates the need of a measurement of signal intensity which is based upon the ratio of signal strength to that of normal strays, for a given detector organization, rather than upon the mere audibility of signals in the absence of strays.

Leonard F. Fuller (communicated): Dr. Austin's work upon transmission formulas has required a vast amount of exacting and tedious measurement under difficult conditions. This was especially true at Darien where the atmospheric disturbances were very severe. Probably those who have attempted

such measurements can best appreciate the amount of detail, the trying difficulties and the chances of error.

The shunted telephone method is the only practical means developed at present for taking such data and since it involves the human ear, it is not surprising that results taken by different observers, or even the same observer at different times, vary widely. Furthermore, it involves telephone impedance which is determined by telephone resistance and reactance and is a function of the audio frequency.

In the reception of damped waves the group frequency is fairly constant and reasonably well known at the receiver, hence the correct telephone impedance value may be chosen reasonably well for the calculation of "observed audibility." In the reception of undamped waves, however, using an oscillating audion, with beat tone reception, as a detector, the audio frequency is altogether dependent upon the receiver adjustment and may be varied at the will of the receiving operator. In this case, therefore, choice of the proper value of telephone impedance is not an easy matter.

The determination of the correct resistance of the receiver is also a source of error and measured values of h_1 and h_2 are rarely available.

One should bear all these difficulties of observation and chances of error in mind when commenting upon such data as are given in Dr. Austin's paper, and should attempt to adjust the mind to consider differences of 100 per cent. between calculated and observed audibilities as we consider errors of 1 per cent. in many laboratory electrical measurements.

I believe Dr. Austin's formula gives a better approximation of actual results than any yet published. While the formula involving $\epsilon^{-\frac{0.0045d}{\lambda^2}}$ discussed in the paper on "Continuous Waves in Long Distance Radio Telegraphy," "Proceedings A. I. E. E.," Volume 34, number 4 was derived from data taken with considerable care and while it checked Honolulu, San Francisco and Tuckerton, San Francisco data very nicely, it gives absurdly high values of calculated received watts when compared with the values observed in the receiving experiments mentioned by Dr. Austin.

The following experiments, involving the reception of Darien at Honolulu may be of interest, inasmuch as they cover signals in the reverse direction over the same path of 8,500 kilometers mentioned in Dr. Austin's paper.

On May 30, 1915 from 3 to 3:30 P. M., Washington time, (9:30–10 A. M., Honolulu time), Darien transmitted upon a wave length of 15,000 meters and observations of received signal strength were made at Honolulu using an oscillating audion receiver. The variables in the transmission formula were as follows:

$$\begin{aligned}d &= 8,500 \text{ km.} \\ \lambda &= 15,000 \text{ m.} \\ h_1 &= 146 \text{ m.} \\ h_2 &= 120 \text{ m.} \\ I_s &= 90 \text{ amps.} \\ R_r &= 25 \text{ ohms approx.}\end{aligned}$$

The calculated audibility was 1,000.

The observed audibility was determined as follows:

Honolulu reported a shunt of 51 ohms on telephones having an impedance of 5,000 ohms per pair at 500 cycles with a telephone resistance of 2,400 ohms per pair. This gives a reactance of 4,385 ohms on 500 cycles or 8,770 ohms on 1,000 cycles, hence the impedance is 9,070 ohms at this frequency and the observed audibility 180.

Darien was audible at South San Francisco but unreadable.

Prior to and after this test Darien was received at Honolulu many times on wave lengths from 6,000–18,000 meters with similar results, but inasmuch as no previously planned tests were conducted, no further specific statement of observations is possible. It is reasonably probable, however, that during the test of May 30, 1915, conditions were approximately normal between Darien and Honolulu.

On March 27 and 28, 1916, 2:30 to 3:00 P. M., Washington time (9–9:30 A. M., Honolulu time), Darien transmitted in pre-arranged tests to Honolulu. The variables in the transmission formula during these tests were as follows:

$$\begin{aligned}d &= 8,500 \text{ km.} \\ \lambda &= 10,000 \text{ m.} \\ h_1 &= 146 \text{ m.} \\ h_2 &= 120 \text{ m.} \\ I_s &= 79 \text{ amps. on March 27, 1916.} \\ &= 70 \text{ amps. on March 28, 1916.} \\ R_r &= 26 \text{ ohms. approx.}\end{aligned}$$

This gives a calculated audibility of 610 on March 27, 1916, and 537 on March 28, 1916.

The observed audibilities calculated in the same manner as the May, 1915, test were 110 for March 27, and 180 for March 28, 1916.

Since it was earlier in the year, the overland transmission over Mexico was considerably better than in May, 1915, so that whereas in May, 1915, Darien was barely audible at South San Francisco, in March, 1916, the signals were easily readable. Darien was also audible but unreadable on a small downtown office receiving antenna in San Francisco in this year's tests.

Continued tests during the months of May and June, 1915, wherein the Darien signals received at Honolulu were expressed in terms of commercial value rather than measured audibilities gave the following results with daylight over the entire path of transmission:—

Honolulu reported consistently that with a radiation of 75 amperes or below, the signals were weak but readable without interference; from 75 to 80 amperes fair, and from 85 to 100 amperes good readable signals. This referred to cipher and code on wave lengths of 10,000 meters and above.

Wave lengths of 15,000 and 18,000 meters gave an audibility ten times that observed on 8,000 meters. The 6,000 meter wave was a little weak but as a rule no great change in signal strength was noticeable from 6,000 to 10,000 meters, the great gain being from 10,000 to 18,000 meters.

At San Francisco the 15,000 and 18,000 meter waves gave better received signals than were obtained on waves of 10,000 meters and below, but on account of the increase in atmospheric disturbances they were no more readable than the shorter waves.

It is to be noted therefore that at Honolulu in March of this year, a 10,000 meter wave gave the same observed audibility as waves of 15,000–18,000 meters in May, 1915, and at San Francisco a considerably greater audibility.

Dr. Austin's Darien observations show calculated audibilities approximately four times the observed, suggesting as he mentions, the possibility of correcting h_1 and h_2 in the ratio found necessary at Arlington. However, the observed and calculated values check very well when receiving at the Bureau of Standards.

In the tests of Darien received at Honolulu, it is again to be observed that if calculated audibilities are altered by correcting h_1 and h_2 in the Arlington ratio the results approach more nearly the observed values.

The receiver resistance values for the receiving experiments at Honolulu are altogether approximations. I believe it would be of interest to many of the members of The Institute of Radio Engineers if Dr. Austin would describe in detail the method he used in determining this value in his work. A statement of his ideas on the error introduced by telephone impedance changing with audio frequency and the probable percentage error in his observations neglecting any errors in the h_1 and h_2 values would be most valuable.

Edwin H. Armstrong: Before discussing this paper, I would very much like to have a little more information about the operation of the apparatus that Dr. Austin used. I am fairly familiar with the regenerative audion and its use as a self-heterodyne, but nothing seems to have been published about the manner of operation of this so-called "ultraudion." This occasion is the first opportunity I have had for getting some first hand information about it, so I am going to ask Dr. de Forest if he will not be good enough to explain how it works. In the absence of an explanation by Dr. de Forest, I wish to advance the following explanation.

You might expect from the name that there is something super-mysterious about the action of this device, and from the manner in which the ultraudion circuit is drawn there is good ground for this belief. But when the circuit is re-drawn as in the accompanying sketch, it becomes at once evident that it is an ordinary regenerative circuit, dependent for its operation on a coupling between grid and wing circuits.

The wing circuit is coupled with the grid circuit thru the combined electrostatic and electromagnetic coupling of the condenser C and telephones T which are located in the common part of both circuits. Thru the medium of this coupling, some of the energy of the radio frequency current set up in the wing circuit by an incoming signal is transferred back into the grid circuit in the manner explained in my paper of March, 1915, in which the identically same form of coupling is shown.

That the arrangement regenerates can be shown experimentally (for the non-oscillating state), by measuring the current set up in the grid circuit by an incoming signal first with the audion disconnected from the rest of the circuit and second, with the audion connected and condenser C adjusted so that the system is fairly close to the point of oscillation. It will be found that the current will have increased very many times over

its value with the audion disconnected. Obviously the audion is supplying energy to the grid circuit and the only source from which this energy can come is the wing battery *B*. A current amplification of 50-fold can be obtained by adjustment of the coupling condenser *C* before the system begins to oscillate.

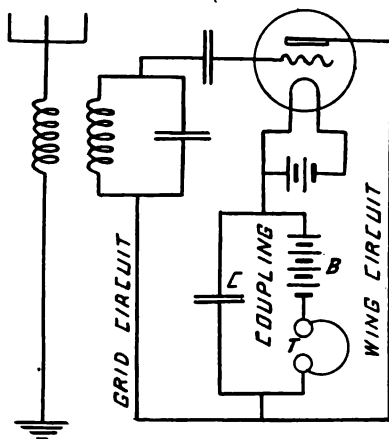


FIGURE 1

After local oscillations start the amplification can no longer be measured in this simple manner, but both theory and practical results show that the amplification due purely to the regenerative action apart from the added heterodyne amplification is markedly increased.

The sensitizing circuit of Dr. Austin is a very ingenious and interesting thing. In the non-oscillating regenerative circuit one can tune the grid circuit exactly to the incoming frequency so that (for continuous waves and loose coupling) the impedance of the circuit is equal to the effective resistance. When you make the system oscillate and receive by the beat principle then the circuit can have zero reactance for the local frequency only, and must oppose a definite reactance for the signaling frequency. The impedance of the circuit for the signaling frequency may thereby be greatly increased, particularly for the longer wave lengths, when the percentage mistuning necessary to produce a note of 1,000 cycles is considerable. What Dr. Austin does to the grid circuit by coupling another circuit to it is to give it two periods so that the reactance of the circuit is zero for two frequencies differing from each other by 1,000-

1,500 cycles. By adjusting the system to oscillate in one of these frequencies and having the other coincide with the signaling frequency the increase in signal strength is secured. It is possible to secure the same effect without the use of the sensitizing circuit by getting the two periods thru the medium of the antenna coupling, but as Dr. Austin points out this requires a relatively strong coupling. Despite the additional adjustments necessary, the use of the extra circuit is well worth while.

Lee De Forest (communicated): I would like to say that I also am in full agreement with the remarks made this evening concerning the uncertainty of audibility measurements. I cannot see that when "audibilities" of from 5,000 to 20,000 or 100,000 are obtained, we can be expected to handle them mathematically at all. With audibilities in amount up to one or five thousand this is possible, but above that I think we need a new unit. Where audibility comparisons are carried on, extending over a period of several weeks or months, and where different bulbs must be used and adjustments are changed, even if the circuits remain the same, the comparisons must be little better than guesses.

As to replying to any remarks of Mr. Armstrong's, I stated on a former occasion that I must refuse to be drawn into any discussion.

However, I wish to point out that it must be obvious to anyone examining, for example, circuit 1 of the de Forest-Logwood "ultraudion patent," No. 1,170,881, that the ultraudion circuit is not and cannot be a "regenerative circuit." There is only one oscillating circuit. This circuit is such that a sudden change of potential impressed on the plate produces in turn a change in the potential impressed on the grid of such a character as produce, in its turn, an opposite change of value of potential on the plate, etc. Thus the to-and-fro action is reciprocal and self-sustaining. It is "regenerative" in the sense that a reciprocating engine with piston and slide valve is "regenerative," or in the sense that an ordinary electric bell or buzzer, is "regenerative." If any member can obtain comfort from calling the ultraudion circuit "regenerative," he is entirely welcome so to do.

Louis W. Austin (by letter): I think that Mr. Hogan must have forgotten that in connection with the Arlington-Salem tests in 1912, experiments were carried out at the Bureau of Standards and at several other stations within ten miles of

Arlington in which the absolute received currents were measured, and in this way the field strength due to Arlington's radiation was determined. It was found that Arlington radiated like an ideal antenna or semi-doublet of less than half the height of the actual antenna, probably on account of the metal towers. (See "Bureau of Standards Bulletin," Reprint 226, page 74.) This is why the effective height of Arlington is taken as one-half the actual height. It seems probable that most land stations like Arlington and the Washington Navy Yard station have actual radiating heights less than the geometric heights. This may be brought about by imperfect ground conductivity under and near the antenna, or by the losses in the metal masts or towers now ordinarily used in radio installations.

The approximate equality of sensitiveness of the oscillating audion to damped and continuous oscillations was shown by a galvanometer arrangement which I described in the "Journal of the Washington Academy," 6, page 81, 1916. The loudness of signal in the telephones can of course also be compared even tho the notes are not the same, using a sending circuit which is first excited by a buzzer and then by an audion, the radio current in the circuit and the wave length remaining the same. In this case owing to the difference in note the audion signals seem to be about three to four times stronger than those from the buzzer.

It is perhaps not generally known that the remarkable sensitiveness of the oscillating audion depends very little on the presence of beats. Using broken up audion excitation with the receiving circuit tuned so closely to the incoming signal that no beats are heard, the signal is about one-third as loud as when the sending waves are not broken up but are received by the beat method with the best note for telephone sensitiveness.

The constancy of the audion when the circuits are adjusted in a perfectly uniform manner is remarkable, being quite equal, I believe, to the electrolytic. Different bulbs, except when evidently abnormal, also give sensibilities which agree within 20 or 30 per cent. The apparent variations are usually the result of imperfect adjustment. In this work the regular bulb was frequently tested by replacing it by a second bulb which could be instantly connected.

The first estimate of the absolute sensibility of the oscillating audion, assuming that it was 1,000 times as sensitive as the electrolytic at unit audibility, and that the electrolytic with the same telephones would respond to 1.225×10^{-9} watts in the antenna, gave 1.225×10^{-15} watts as its sensitiveness. Since

that time, further determinations have been made employing several different bulbs and different wave lengths. The method employed was the comparison of the deflection of a galvanometer connected to a silicon detector with the audibility observed with the oscillating audion. The same secondary circuit was used in both cases and the audion or detector thrown in by means of a two way switch, adjustments for tuning and best coupling being independently made in the two cases. The detector was calibrated by comparison with a thermo-element in the artificial antenna immediately before each experiment. The sending apparatus was a wave meter excited by a powerful audion. The average value of the energy for unit audibility on the audion was found by this method to be 1.5×10^{-15} watts in the receiving system. A paper on this and some connected lines of work is now in preparation.

As Prof. Zenneck suggests, it would of course be desirable to use a detector and galvanometer in all measurements of received signals, but in general for long distance work this is impossible.

If the detector is sensitive enough to produce deflections for weak signals, the atmospheric disturbances during a great portion of the time will make the readings even more unreliable than those taken with shunted telephones. I fully realize that the telephone method is far from satisfactory, altho it has been shown that telephone audibility, as taken by our methods, is proportional to the received antenna current in the case of the audion. This is shown in the following table of observations taken in the Naval Radio Laboratory with an artificial antenna.

Audibility	Radio Current	Audio Current
250	11	23
400	16	25
1,500	58	26
2,500	99	25
4,000	148	27
4,500	160	28

The experimental errors of the audibility measurements under station conditions amount frequently to 30 per cent. and the observation may sometimes be incorrect in the ratio of two to one, but except when the signals are nearly masked by heavy atmospherics, I do not believe that the errors are greater

than this. Bad as this is, it is certainly much better than no observation at all. The most disappointing fact in our work is the great irregularity in the signal strength which renders any comparison with the theory extremely unsatisfactory.

In heat reception, the telephone sensibility rises with the pitch of the note, but this is partly counteracted by the secondary circuit becoming more and more out of tune with the signal as the note rises. In addition, the audibility reading is lowered, due to the increase in telephone impedance. Thus, these effects to a considerable extent counterbalance each other over the range where the loudest signals are heard. If the operator readjusts for loudest signal after the audibility meter is set near the point of silence, the error due to these causes is not great, as is shown by our direct comparison of audibility and sending current using artificial circuits.

The resistance of the receiving system can be best determined, where continued oscillations are available, by exciting the antenna from a loosely coupled undamped circuit and then introducing enough resistance to reduce the antenna current to one-half. As the audibility meter is calibrated by comparison with a silicon detector and galvanometer, the amount of coupling resistance added in the calculations is that due to the silicon detector circuit. This, for best coupling, is always roughly seven-tenths of the antenna resistance.